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Assessing water use and quality through youth participatory research in a rural Andean watershed

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ABSTRACT

Water availability, use and quality in a rural watershed of the Colombian Andes were investigated through participatory research involving local youth. Research included the quantification of disaggregated water use at the household level; comparison of water use with availability; monitoring water quality of streams, community water intakes and household faucets; and the determination of land use – water quality interactions. Youth were involved in all aspects of the research from design to implementation, dissemination of results and remediation options. Quantification of domestic and on-farm water use, and water availability indicated that water availability was sufficient during the study period, but that only an 8% decrease in dry season supply would result in shortages. Elevated conductivity levels in the headwaters were related to "natural" bank erosion, while downstream high conductivity and coliform levels were associated with discharges from livestock stalls and poorly maintained septic tanks in the stream buffer zone. Through the involvement of youth as co-investigators, the knowledge generated by the research was appropriated at the local level. Community workshops led by local youth promoted water conservation and water quality protection practices based on research, and resulted in broader community participation in water management. The approach involving youth in research stimulated improved management of both land and water resources, and could be applied in small rural watersheds in developed or developing countries.

1. Introduction

Water and sanitation services throughout rural Latin America are undersupplied, with 40% of households lacking access to drinking water and 50% lacking basic sanitation (WHO, 2000; PAHO, 2001). The provision of water services in rural regions is typically the responsibility of community organizations (Foster, 2005), but many small communities cannot afford water treatment plants or provide continuous service with equal characteristics of urban regions. In Colombia, there are more than 25,000 small scale water and sanitation systems, 80% of which are community based (Vargas, 2001). Only 4% of these small supply systems have water treatment facilities, and only 65% are operating (Ministerio de Ambiente, 2004). This situation is not atypical of rural communities throughout the Andes, where both intermittent supply and poor water quality are of concern.

To satisfy the water needs in rural areas, the water requirements for the subsistence of poor families must be specifically taken into consideration, including activities such as livestock care, kitchen gardens and crop production in addition to domestic consumption (Perez et al., 2004). Normally the use of water for productive activities is prohibited in the domestic distribution systems managed by rural aqueducts, but because these activities sustain the rural poor, users withdraw water for unauthorized productive uses or alternatively water designated for irrigation is used to meet their domestic needs (Van der Hoek et al., 1999); both alternatives affecting the availability and quality of water. The use of "potable" water for all activities has become common, and other sources such as rainwater harvesting or grey-water re-use have been largely ignored in much of Latin America (Restrepo, 2005).

One factor that impedes decision making to improve water services in rural areas is the lack and inconsistency of information on water consumption, availability and quality (Roa et al., 2008). Without data, users within a watershed cannot demonstrate causes of contamination and/or over exploitation of the resource, limiting their ability to lobby local authorities for improvements. Knowing water needs, water availability and the way human activities are

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affecting the resource, permits a diagnostic of overall watershed conditions, and the determination of priority sites for intervention.

Participatory research through partnerships between scientists and citizens provides an approach to natural resources management which recognizes the complexity of issues and the need to produce options suited to the end users (Brown, 1985; Finn, 1994). Recently participatory research has been promoted and used internationally to involve local communities in data collection and monitoring (Roba and Oba, 2009; Inmuong et al., 2005), natural resources management research (Johnson et al., 2004), and the effective use of natural resources (Fleeger and Becker, 2008; Sultana and Abeyasekera, 2008). Youth involvement in environmental research, however, is relatively new, but has the potential to promote the local appropriation of research results, facilitate the dissemination of knowledge, and stimulate locally led action (Roa et al., 2008).

In addition to the advantages in rural development obtained from the participation of youth in local research, such programs contribute to environmental education (Roa et al., 2008). The World Bank (2002) lists education as the single most important factor in development and the alleviation of poverty. Environmental education is central to effective community involvement in participatory research, and in the development of outcomes that are relevant and acceptable to the community (Marschke and Sinclair, 2009). Since high quality environmental education is an important first step for achieving sustainable resource use, and youth are the primary target population in which to initiate change, combining the two in participatory research could be highly effective.

Various projects have involved youth in environmental studies (e.g. Kotak, 2006; Goedkoop et al., 2004), but participatory research in general has been criticized for a lack of structure and depth (Gladwin et al., 2002). The objective of this study was to investigate the water needs of rural families for both domestic and productive purposes, to gain an understanding of water availability in relation to its use, and to assess the impact of land management on water quality. A participatory youth research approach was used with the aim of fostering local ownership of the research and improved land and water management which are supported by science.

2. Study area and methods

The research was undertaken in a small rural watershed in Colombia, the Los Sainos micro-watershed located in the municipality of El Dovio (Fig. 1) in the western cordillera of the Colombian Andes. The watershed has an elevation range from 1570 to 1870 m, an area of 447 ha, and encompasses 58 families, 2 schools, and a small natural reserve "la Reserva El Cipres". Water supply in the watershed is provided through two small dams and settling ponds connected to community water tanks (<20 m^3 each) located in the headwaters. Neither source is treated prior to distribution. The watershed is typical of rural mountain watersheds in the region which rely on small, informal water use systems for domestic and agricultural water supply.

The research was conducted in 2004 and 2005, and involved a total of 30 youth, with subgroups involved in specific themes. Youth from 9 to 17 years old were invited to participate in the project through the local schools, and via a youth and natural resource education project active in the region (Roa and Brown, 2005). Youth living in the Los Sainos watershed were specifically recruited, and involved in all aspects of the research including survey design, data collection, analysis and the presentation of results. A watershed assessment methodology was developed and implemented with youth co-researchers, which included the following steps:

1. Development of spatially referenced baseline information for comparative analysis,
2. Mapping of the watershed,
3. Water availability measurements at water intakes,
4. Data collection on water consumption to determine the quantity of water used for specific activities,
5. Water quality analysis at water intakes, streams and homes,
6. Evaluation of results with the community and local decision making on management alternatives,
7. Implementation of priority alternatives,
8. Re-evaluation of water quality and availability through monitoring pre and post change.

2.1. Participatory baseline survey and mapping

A questionnaire relevant to local farming practices and water resources management was designed, field tested and implemented in 2004. Youth were involved in the design, implementation and analysis of the surveys. The farm surveys were conducted in groups of two or three youth, with one scientific advisor accompanying each group in the field. Information was gathered on water sources, shortages, perception of water quality, grey-water treatment, land use and livestock numbers. The majority of households in the watershed ($n = 54$; 98%) were interviewed, and preliminary results were reviewed by the group daily in the field. The location of all households was geo-referenced using a handheld GPS and later transferred to GIS. The survey results were compiled and analyzed jointly by the youth and team scientists. The findings were then presented by the youth to their community in a series of workshops with discussion on further information needs and alternative management options.

Land use was mapped using a 2004, 1 m resolution Ikonos™ image and field verified. Household locations were geo-referenced and linked to the household survey data. The stream network was field mapped onto the image, all water quality sampling locations were marked, and a buffer zone analysis of land use within 30 m of the stream was conducted. The GIS work was undertaken jointly with youth co-researchers who were trained in ARCView™ GIS, and supervised by a GIS technician at the municipal telecentre.

2.2. Water use and availability

As the majority of the houses in the watershed do not have water meters and since measurements of water use for individual components within the household/farm was of interest, a household water audit was conducted (MDE, 2007). Water use was measured in 18 of the 58 houses in the watershed between December 2004 and September 2005: 6 in the upper watershed, 6 in the mid-watershed, and 6 in the lower section (Fig. 1), and measurements were repeated on 3 separate dates per household. Water consumption was quantified for domestic activities such as toilets, personal hygiene, cooking and drinking, dishwashing, laundry, and household chores. Measurements were made from 7:00 am to 5:00 pm, and total water use during a 24-hour period was estimated as an additional 1/3 for dishwashing and personal hygiene based on key informant interviews. Water use for productive activities such as crop irrigation, stable cleaning and post-harvest water use in coffee production were also quantified. Domestic activities were measured in all of the sampled houses, while productive activities were only measured in selective households representative of the dominant crop and livestock types within the micro-watershed. A series of methods were developed including gauged faucet flow, calibrated containers, tabulation sheets and measurements of flow within water pipes.

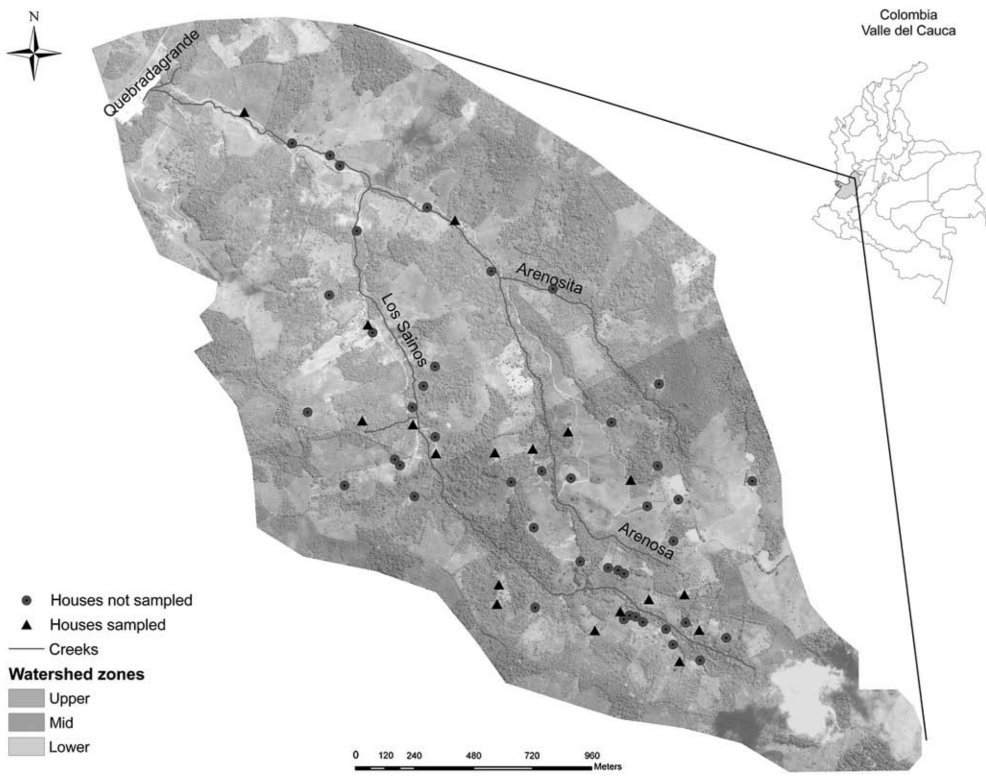

Fig. 1. Study area.

Youth were trained in the application of these techniques and worked in pairs to monitor daily water use, with limited technical support.

Water flow from every indoor faucet and outdoor tap was gauged with a 500 ml graduated cylinder and stopwatch. For each activity, the time that the faucet was opened was measured (seconds) and multiplied by the faucet's water flow (L/s) accounting for the degree of opening identified (i.e. number of turns). The resulting value estimates the volume of water (*L*) used for that specific activity. Examples of activities measured with this technique include dishwashing and pig stall cleaning using a hose. For large aperture openings, such as shower heads or hoses, the same method was applied but utilizing a larger volume to gauge flow, typically 10 L.

Activities such as house cleaning (mopping), laundry, and drinking water for livestock often utilize containers to provide water. To determine the amount of water used, the volume of the container was measured and multiplied by the number of times that the container was used, giving the total volume (*L*) of water used for that activity. In some instances, such as cattle watering, small containers are not used, but water is drawn from large tanks. In this case, the volume drop in the tank was measured to determine daily water use. To determine the volume of water used by toilets, the volume of the toilet tank was measured by the amount of water required to refill the tank (*L*). The number of times the toilet was flushed during a 24-hour period was noted and then multiplied by the volume (*L*) of the toilet tank.

The quantity of water was measured from the two main water intakes of the Los Sainos stream, the primary source of water for the micro-watershed, along with precipitation and downstream flow. The quantity of water supplied at the intake in the headwaters was estimated by installing a T-value in the one inch outlet pipe, measuring the amount of time to collect 10 L, and calculating the flow (L/s). Fifty-five dates were sampled between June and September 2005, with three repetitions per date. As 100% of the available water is collected during the dry season, this method provides a rough estimate of availability during this period for comparison to water use. Two youth co-led the water quantity component of the study, taking measurements and coordinating with the team hydrologist.

2.3. Water quality

Water quality sampling followed the design of Ponce (1980) in 4 stages: reconnaissance, baseline, cause and effect, and compliance.

A reconnaissance survey of the streams was conducted, measuring conductivity, pH, DO, TDS, and T ($n = 44$) in the field at points of land use change from downstream to upstream (Fig. 2). From this information, strategic sites were identified for baseline monitoring ($n = 16$), and sampling was repeated temporally on 5 dates during the period June to September 2005. Additional sites with significant change in water quality (based on field reconnaissance) were identified for in-depth exploration of interrelationships between land use and water quality ($n = 5$). These land–water interactions were investigated by sampling in the stream reaches above, in and below the site, and comparing the water quality results to land use information in the 30 m buffer zone obtained from GIS analysis, field surveys and questionnaires (i.e. # animals, septic systems, grey and black water treatment, access of animals to the stream).

Water samples were collected from kitchen faucets in 15 of the 18 households where water consumption was measured to determine if the rural water supply system without treatment fulfilled Colombian norms for potable water. In one household, two samples were collected pre and post sand filter treatment to determine the effectiveness of this process. Household water quality sampling was conducted twice during the study period.

Headwater sources, stream monitoring sites and in-household "potable" water samples were analyzed for: turbidity, pH, temperature, conductivity, total dissolved solids and dissolved

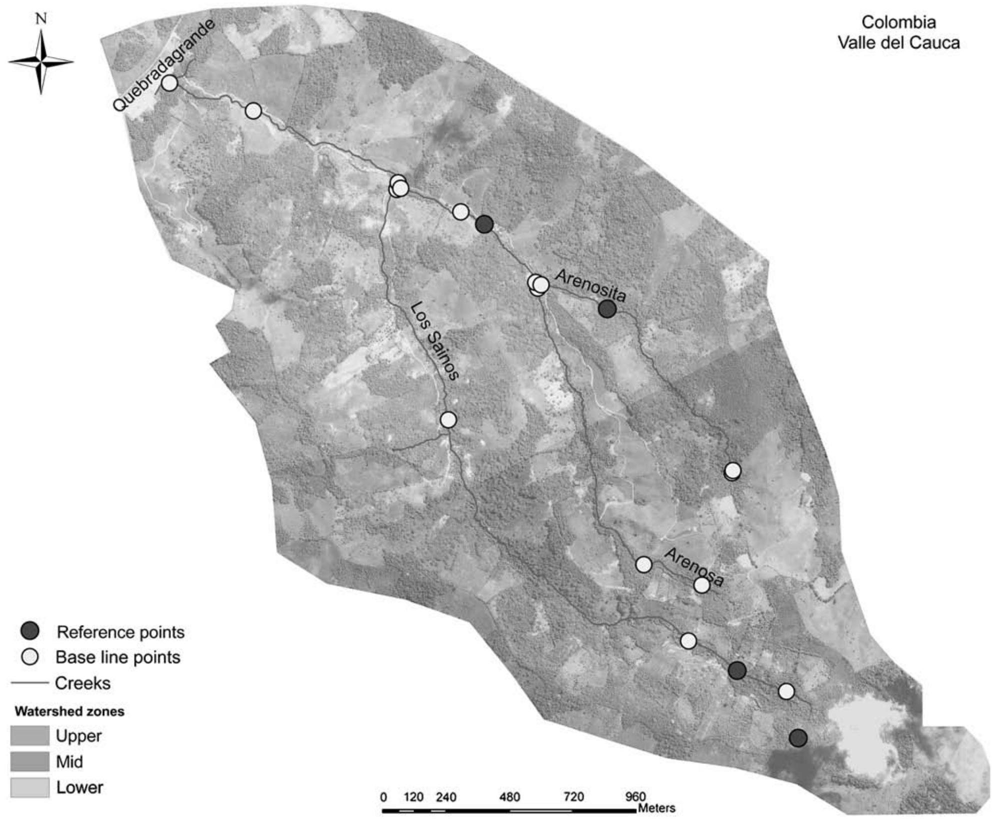

Fig. 2. Water quality sampling design.

oxygen using portable meters; nitrate and phosphate using a portable spectrophotometer; Ca, Mg and hardness using a titration kit (Hach, 2007); and fecal and total coliforms using a portable incubator (RCPEH, 2004). The results for water quality were compared to Colombian norms for potable water (Decreto 475 de 1998. Ministerio de Salud, 1998) and for recreational, agricultural, and livestock use (Decreto 1594 del 26 June 1984, Ministerio de Agricultura, 1984), and to WHO drinking water quality guidelines (WHO, 2004). Youth were actively involved in the water quality component of the project, including field monitoring, sample collection and laboratory analysis under the co-lead of the team environmental chemist.

A series of workshops were organized where the youth presented project results to the watershed community, and potential options to improve land and water management were discussed. Seed money was provided for materials along with in-kind labour from the community to implement priority options.

3. Results and discussion

3.1. Baseline survey and mapping

The principal land use activities in the micro-watershed are cattle ranching, farming, and poultry and hog production (Tables 1 and 2). A typical rural household in the watershed is comprised of four persons, one dog, ten hens, five pigs and five cows, has 9 ha of land, 350 m^2 of cultivated land, and a kitchen garden. However, there are significant differences in land use between the upper, middle and lower sections of the watershed with the majority of cattle pasture located in the lower portion of the watershed, and crops and forest land in the mid to upper sections. Similarly the distribution of livestock varies with the largest number of poultry in the lower watershed, hogs in the upper watershed, and cattle in the lower and upper sections. The majority of poultry (80%) and milk (60%) produced are for home consumption, compared to 90% of pork and 80% of beef destined for local markets. The principal annual crops are maize, coffee, beans and yucca with most families growing a mix of crops for both home consumption (40%) and the local market (60%) (Roa and Brown, 2005).

The majority of households obtain water from one of two community water intakes located in the headwaters for both domestic and agricultural/livestock purposes. Households report significant water shortages in July and August (the "long" dry period), perceive sediment as the major water quality concern, and boil their water prior to human consumption. The only other water users in the watershed are two small schools and the reserve which has a small guest house.

3.2. Water use

Domestic water consumption results are shown in Table 3, and for comparison, recommended levels for aqueduct design in

Table 1
Principal land use activities in the Los Sainos micro-watershed.

Section of watershed	Protein bank[a]	Domestic food crops[b]	Annual crops	Forest	Cattle pasture	Other
Lower	0%	2%	35%	9%	54%	0%
Middle	0%	4%	46%	15%	35%	0%
Upper	2%	3%	41%	15%	29%	10%

[a] A protein bank is a cut and carry fodder stock to provide supplemental feed for livestock.
[b] Domestic food crops are products for home consumption such as carrots, onions, herbs.

Table 2
Distribution of animals and people in the micro-watershed.

Section of watershed	ha	Cattle	Hogs	Poultry	Persons	Cattle/ha	Hogs/ha	Poultry/ha	Persons/ha
Lower	246	89	80	322	64	0.36	0.33	1.31	0.26
Middle	89	31	21	159	49	0.35	0.23	1.78	0.55
Upper	112	70	88	160	66	0.63	0.79	1.43	0.59

Colombia and domestic water consumption in Canada are also given. Domestic consumption in the Los Sainos watershed averaged 67 L/capita/day, which is at the lower level of recommended supply for Colombia. When productive consumption was considered, and water requirements for animals, cultivated land and gardens were included, the maximum daily consumption rises to 191 L/capita/day. This is a maximum value as crops are not irrigated daily, but rather every three days during the dry seasons (January to February and June to August). For the typical farm, the amount of water used for irrigation was 137 L/day. If a household cultivates coffee, an additional 230 L/day was required for post-harvest coffee washing, bringing the household maximum water use up to 250 L/capita/day. This amount approximates the upper limit proposed for domestic consumption (240 L/capita/day, Table 3). Thus in the design and management of rural water supply systems, the concept of multiple water uses is critical as these "other" forms of water consumption for subsistence purposes are as essential as domestic water consumption activities (Restrepo, 2005).

The relative distribution of water consumption (daily average) between domestic and productive uses is shown in Fig. 3. Agricultural water withdrawals (livestock and crops) account for roughly 2/3 of water use, with livestock accounting for only 15%. Comparing water consumption between the upper, middle, and lower sections of the watershed, significant differences were not observed. The main difference was in the amount of water used for pig stall cleaning in the different regions of the watershed (Table 4). Consumption in the upper watershed was significantly less than in the lower region due to a difference in the method used to clean the animal pens (nozzle versus a running hose), and points to the opportunity for the implementation of simple water conservation measures through farmer to farmer knowledge transfer.

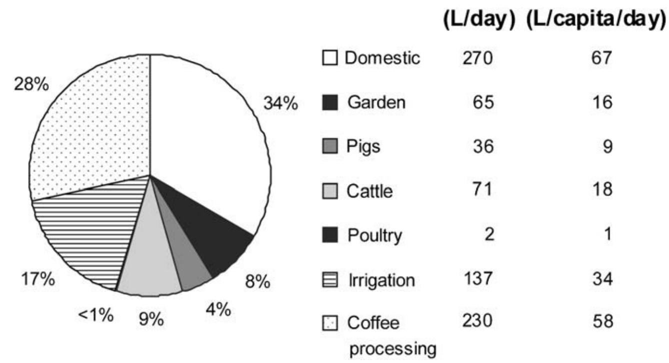

Fig. 3. Domestic and productive water consumption.

3.3. Water availability

The flow of water captured in the upper water intake (1 of 2 systems in the watershed) during the dry season (mid-June to beginning of September 2005) was on average 0.09 L/s. This flow supplies water for eight households (34 persons, 20 of which are not permanent residents), their animals, crop irrigation, and coffee washing. This water supply, however, is subject to losses within the distribution system and may be adversely affected during extended dry seasons. The average water loss in distribution networks for Latin America is estimated at 40% (ADERASA, 2005). Assuming a conservative 30% distribution loss, availability in the study period exceeds estimated consumption by only 394 L/day (Table 5). With only an 8% reduction in the water captured, the difference between use and availability becomes negative. Precipitation over the last 20 years at the nearest two national climate stations (Versalles and El Dovio) averaged 1433 and 1428 mm/year respectively (IDEAM, 2005), but includes dry years with 40% less precipitation making a 10–20% reduction in water availability a feasible scenario.

3.4. Water quality

Reconnaissance sampling results for stream water quality show an increase in conductivity and in total dissolved solids from upstream to downstream (Fig. 4). In the upper watershed, throughout the protected zone "S3" (Fig. 4), an increase in conductivity was observed, however, there were no obvious anthropogenic sources of contamination. In order to verify the source of elevated conductivity levels, cause and effect samples were taken at additional points along the stream reach, and conductivity and total and calcium hardness were measured. A correlation of 99.88% between conductivity and hardness in the upper stream reach was found suggesting that elevated conductivity levels were related to "natural" bank erosion. This correlation was not observed at point "A11" (Fig. 4), where there were significant discharges of excrement from pig stall cleaning. At point "a6"

Table 3
Domestic water consumption.

Activity	Los Sainos micro-watershed (L/capita/day)		Colombian aqueducts (L/capita/day)[a, b]		Canadian average (L/capita/day)[c, d]
	Min	Max	Min	Max	
Shower	8	15	–	–	100
Personal hygiene	1	4	–	–	18
Sub-total personal hygiene	9	19	20	75	118
Dishwashing	10	12	–	–	7
Food and Drink	3	4	–	–	33
Sub-total kitchen	13	16	15	30	40
Laundry	25	29	10	20	75
Toilet	11	16	30	40	100
House cleaning	4	5	5	75	2
Total domestic consumption	62	85	80	240	335 (290–541)

[a] Corcho Romero, 2005.
[b] López Cualla, 2006.
[c] NRCAN, 2007.
[d] Environment Canada, 2004.

Table 4
Livestock water use.

	Sainos Consumption (L/Animal/day)			Consumption literature (L/animal/day)[a]
	Lower	Middle	Upper	
Cattle	8	–	14	45
Pigs	47	–	10	16
Hens (× 100 animals)	21	15	37	20–40

[a] Ramirez, 1992.

Table 5
Consumption versus water availability in the upper Los Sainos water intake.

Livestock Consumption	# animals	L/animal/day	L/day	Total (L/day)
Cows	14	14.24	199	
Pigs	45	7.25	326	
Poultry	27	0.20	5	530
Domestic Consumption	# inhabitants	L/capita/day	L/day	Total (L/day)
	34	67	2278	2278
Agricultural Consumption	Cultivated area (m^2)	$L/m^2/day$	L/day	Total (L/day)
	2200	0.9	2011	2011
Coffee Washing Consumption	# Farms producing coffee	L/washing/day		
	1	230	230	230
Availability (L/day) assuming 30% distribution losses				5443
Difference (L/day)				394

(Fig. 4) there was also an increase in the measured parameters, potentially related to discharge into the stream from a malfunctioning septic tank.

For the sixteen baseline monitoring sites established on stream tributaries, two parameters did not meet the criteria for potable water set by the Ministry of Health in decree 478 of 1998 (Table 6). Total coliforms had 0% compliance (0 CPU/100 mL) (Fig. 5); and phosphates had 0% compliance for potable water (<0.2 mg/L PO_4^{-3}) and 50% compliance for safe water (<0.4 mg/L PO_4^{-3}). Fecal and total coliforms were present even in the forested headwaters. In 88% of the sample points, pH levels (6.5–9.0) met the requirements, the exception being in the upper watershed and wetland sites. Turbidity complied with the norm (<5 NTU) in only 40% of the sample points and high levels are likely related to unstable stream banks in the upper region.

The parameters that met the requirements throughout the entire watershed were calcium hardness (<100 mg/L $CaCO_3$), total hardness (<160 mg/L $CaCO_3$), conductivity (50–1000 μS/cm), total dissolved solids (<500 mg/L), and nitrates (<10 mg/NO_3–N). With respect to water quality norms for recreational, agricultural and livestock uses (Decreto 1594 del 26 Junio de 1984, Ministerio de Agricultura, 1984) only fecal and total coliforms did not meet the requirements. The norm for total coliforms is 1000 CPU/100 mL and 5000 CPU/100 mL for recreational and agricultural purposes, and the compliance rates were 63% and 100% respectively.

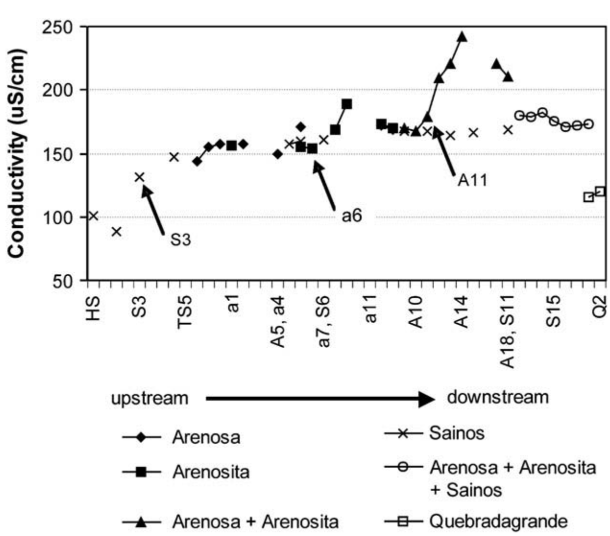

Fig. 4. Conductivity from upstream to downstream.

A close relation can be demonstrated between land use and water quality. The mitigation of land use impacts on water quality were demonstrated through existing treatment systems such as septic tanks, bio-digesters, and canals and lagoons with aquatic plants, since degraded water quality conditions were not observed in downstream reaches. The negative impacts of land use on water quality were monitored downstream of untreated fecal discharges from pig stalls and non-maintained septic tanks. Access to the stream by cattle did not appear to significantly increase the amount of coliforms in comparison with fecal discharges from animal stalls adjacent to streams. The water quality parameters which varied most with land use changes were conductivity, dissolved solids, fecal and total coliforms, nitrate and phosphate. Parameters such as temperature, pH, dissolved oxygen, turbidity, calcium and total hardness were related more to the area's topography and geology than to land use.

The results of the water quality samples taken from household faucets indicate that coliforms and turbidity do not meet the requirements set in decree 478 of 1998 (Fig. 6). In half of the houses in the watershed ($n = 29$), turbidity levels were greater than 5 NTU, and fecal coliforms were consistently greater than 0 counts/100 mL. These results are consistent with the baseline stream monitoring, and suggests that contamination in the headwaters is a major concern for domestic water supply. Only one of the 58 families has a sand filter. In this house, turbidity, fecal and total coliforms were reduced after treatment: fecal coliforms to zero and turbidity to permissible levels.

3.5. Participation and action research

Youth participation in all aspects of the study was a key factor in creating a dialogue on water resources issues within the watershed and in the adoption of recommendations at the site scale. Involvement in the design and evaluation phases of the project facilitated the adaptation of scientific approaches to local conditions, and brought local knowledge of soil conditions, water distribution, farming practices and local environmental practices to the project team.

Youth participants co-led community workshops, presenting research results and discussing management alternatives with community members. At the workshops, current land management impacts on water quality and use were discussed, and alternative methods to improve management were proposed. Community members had the opportunity to share their experiences about issues and practices in the watershed, such as the custom of cutting down stream riparian vegetation to minimize cover for poultry predators. Recommended better management practices included water re-use, rooftop water harvesting, automatic shutoffs on animal watering tanks, and the use of hose nozzles. Many better management practices were already in use in the watershed, but by a limited number households; farmer to farmer knowledge transfer proved beneficial in replicating locally successful practices such as the use of nozzles in stall cleaning. Decisions agreed upon and undertaken by the local community included the installation of a sand filter for drinking water at the elementary school in the lower watershed, septic system maintenance, water intake maintenance, the promotion of biogas, and the construction of bio-retention works in the headwaters in an attempt to minimize sediment from bank erosion. Biogas was seen as an environmentally useful option to reduce the discharge of animal waste into streams, but the capital costs (US$250) were

Table 6
Water quality results for baseline monitoring.

Variable	Decree 475 of 1998[a]		Maximum value in sample	Compliance rate in sample (%)	Compliance	Factors in non-compliance	Factors in compliance
	Potable Water	Safe/Secure Water					
Conductivity (μS/cm)	50–1000	≤1500	240	100%	Complies	–	Compliance but increases with manure/feces
Total Dissolved Solids (mg/L)	<500	<1000	130	100%	Complies	–	
pH	6.5–9.0	6.5–9.0	6.0–9.0	88%	Does not comply in wetland and Arenosita source	Soil/land sediments in wetland and headwaters	No chemical contamination
Turbidity (NTU)	<5	≤5	12	40%	Does not comply	Sediments	–
Fecal Coliforms (CPU)	0	0	Excess growth	0%	Does not comply	Fecal contamination from pig stalls and septic tank discharges	–
Total Coliforms (CPU)	0	0	Excess growth	0%	Does not comply	Microorganisms in soil and vegetation	–
Calcium Hardness (mg/L $CaCO_3$)	<100	<120	40	100%	Complies	–	No chemical contamination
Total Hardness (mg/L $CaCO_3$)	<160	<180	90	100%	Complies	–	No chemical contamination
Phosphates (mg/L PO_4^{-3})	<0.2	<0.4	1.4	0% Potable 50% Secure	Does not comply	Manure	–
Nitrates (mg/L NO_3–N)	<10	<10	1.6	100%	Complies	–	No excess fertilization

[a] Technical norms for potable water quality.

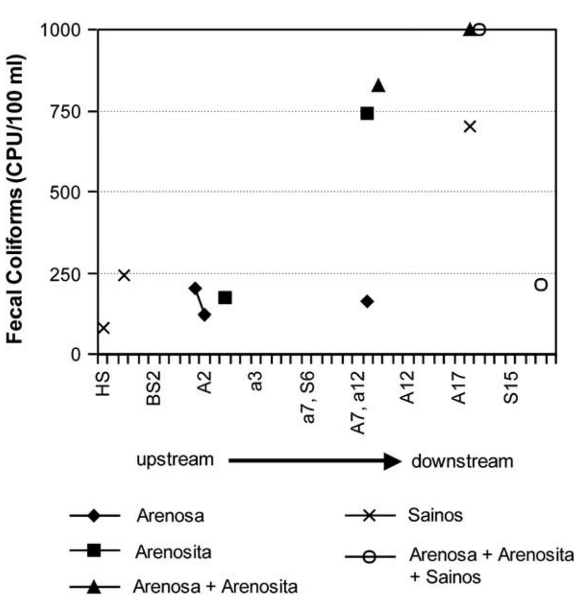

Fig. 5. Fecal coliforms in baseline stream monitoring samples.

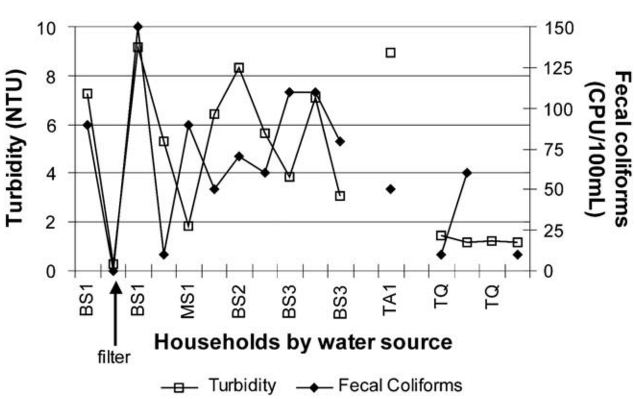

Fig. 6. Turbidity and fecal coliforms in water from household faucets.

prohibitive, and financial support was necessary, limiting its application. Bioremediation works were constructed above the community water intakes using bamboo retaining walls and live fencing. Community members from both the upper and lower watershed contributed time and local materials. The sand filter installed at the school was constructed by community members knowledgeable of the technology. Coliforms and sediment levels were reduced to potable standards and the filter performed well over time.

4. Summary and conclusions

Youth co-investigation of water use, availability and quality led to an understanding of the multiple uses of water at the household, farm and micro-watershed levels. The importance of agricultural and livestock water needs in addition to domestic supply was shown, along with the limited capacity of the current distribution system to cope with climatic variability. Domestic water use averaged 67 L/capita/day; but 191 L/capita/day were required when productive uses of water (crops and livestock) were included, and 250 L/capita/day with post-harvest water use. Water availability during the dry season was roughly equivalent to water use, and only an 8% reduction in water capture would result in shortages. Due to limited capacity to store water, the community is vulnerable to climatic variability, and dependent on the ecosystem to regulate low flows.

Both natural and anthropogenic sources of contaminants were identified, with anthropogenic sources dominating in the lower watershed. Elevated conductivity levels in the headwaters were related to bank erosion. Downstream high conductivity and coliform levels were associated discharges from livestock stalls and poorly maintained septic tanks in the stream buffer zone. Water samples taken from household faucets did not comply with coliform or turbidity requirements, and coliforms were present even in the forested headwaters, pointing to the need for additional source water protection. Direct youth involvement in the research led to their appropriation of the results, and facilitated discussion with the local community on current practices and options to improve land and water management. Knowledge of treatment strategies (e.g. sand filtration) was already present in the area, and provided a stimulus for implementation, but the community was open to actively participate in alternative strategies, such as bioremediation.

Working with youth in watershed research raised awareness of environmental issues amongst the youth themselves, and allowed them to raise awareness amongst their peers and adults in the local community. A significant aspect of this project was the development of an approach to watershed assessment which involved youth in all aspects of the research. This process was found to advance environmental education, and knowledge of research methods and local environmental impacts. While institutional support from a NGO, university or research center was required to provide training and technical support, the approach was able to stimulate locally lead action. This youth participatory research methodology could be applied in small rural watersheds in developed or developing countries, and adapted to a range of environmental issues. Drawing upon the willingness of youth to learn and their interest in investigating issues of local relevance, community appropriation of the research was fostered and science brought into local decision making.

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